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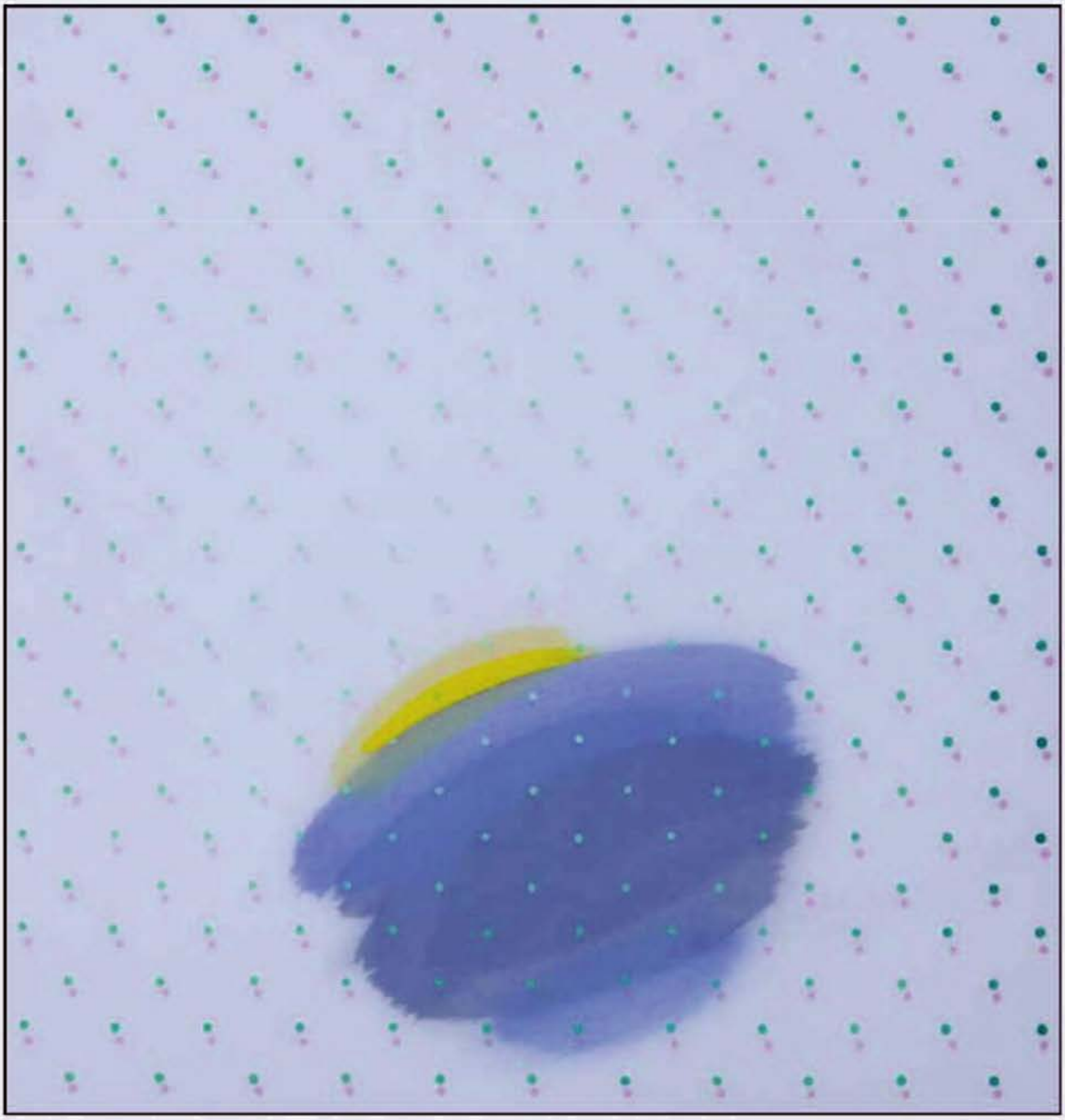

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Editorial

These past few weeks, the Editorial Board at the South East European Journal of Sustainable Development has been a hive of activity as we have doubled our capacity in order to meet the increasing supply of academic articles to review for publication. This – already third annual - issue of SEEJSD is the direct result of scholars' increased research activity across the scientific spectrum. A glance at the broader landscape of research and writing at present sees this as scarcely a surprise. The COVID-19 pandemic has brought about a rapid shift in priorities in the world of science which has also inevitably affected the world of academic publishing. While the sudden unified focus on the coronavirus transformed what and how scientists study, the unprecedented circumstances that it imposed on the habitual and the everyday affected the volume of studies, as reports suggest that 2020 witnessed a sharp increase in articles across all subjects being submitted for publication in scientific journals.

Under this strain of a swelling pool of research and shorter time between submission and publication, the scientific community, and particularly any journals that aim to maintain their reputation and influence, are poised before the challenge of balancing the benefits of the rapid emergence of new research insights against the potential damage from diminished publication standards. As we at the Editorial Board of SEEJSD understand the Journal's accountability in contributing to the issuance of authentic new research, we have enhanced our review infrastructure in order to be better able to accommodate and honour valuable new submissions without compromising the rigorous editorial standards that we have nurtured for years in our effort to establish a journal that publishes relevant and cutting-edge research in sustainable development and upholds the values of transparency, reproducibility and consistent quality.

It is thus a source of immense pride for us to share the news that SEEJSD has been successfully evaluated for inclusion in EBSCO's full-text subject-specific database. Indexing is vital to the reputation, reach, and consequently impacts of journal articles. As researchers and scholars, we understand too well that academic indexes are typically our chief starting points when we embark on new scientific explorations. At the same time, as indexing has come to represent a hallmark of journal quality, having a submission referenced in a journal that is included in a leading index is a priority for many scholars. Hence, SEEJSD's indexing nomination is at once an effect, i.e. a crowning achievement of years of dedication to developing a reputable platform for the promotion of groundbreaking academic research and a cause, i.e. a driving force spurring us on to even more committed work in the future as we aim to achieve a reliable impact factor.

As we prepare to undertake the challenge of meeting both the real and the scientometric standards of quality academic publishing, we invite our researchers and readership to join us and contribute to building SEEJSD's story of success.

Cordially,

Dr. Azis Pollozhani, PhD
Editor-in-Chief

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Application of new Mathematical Models in the Higher Education Evaluation Process

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Abstract

The current situation with the reforms conducted in the last several years in Republic of North Macedonia, in terms of higher education do not give the expected results regarding the positions Universities have at the international rankings. Based on the Ministry of Education and Science, there are currently 17 accredited higher education institutions in the state and still there is not relevant, deep and comprehensive analysis conducted about their work. Working in the field of higher education showed that there is a possibility (still not automated and integrated) to examine the quantitive outputs in terms of educated staff, as well as scientific work and visibility in the Internet (Scopus, Webometrics, other sources), but the quantitive aspect is missing, as well as the comparison in between with locating the best of the best, thus knowing what are the best practices and who is conducting them. Also, there is lack in the approach of comparison the outputs with the inputs (what has been invested to produce those outputs) and answer the question of what is the price paid (not only in terms of finances, but broader). Bearing this in mind, the efficiency of our Universities is still a black box and for sure we claim that not being aware about it, we cannot hold any successful reform in the educational system and achieve higher goals and international rankings. The purpose of this work is to propose a new ways of evaluation the higher education system which could be applied not only for the domestic Universities. Mathematical modeling is used with elaboration of several specific methods, such as DEA, AHP, SFA etc. Some of them already applied in qualitative and/or quantitative evaluation of some parts of our educational system.

Keywords*: DEA – Data Envelopment Analysis, AHP – Analytic Hierarchy Process, SFA – Stochastic Frontier Analysis.*

Current situation and analysis

There are a lot of publications that can be found in academic circles, concerning efficiency of educational institutions. Maybe one of the most important question to be answered is what is the most appropriate method to be used in the process of evaluation of the efficiency of higher education systems. For sure, the best approach would involve deep research and consideration of the recent publications from the reputable publishers, institutions and authors.

Data envelopment analysis (DEA) is used to make an evaluation of the relative efficiency of around 500 higher education institutions (HEIs) from Europe and USA, between 2000 and 2010. Different input-output sets were applied with specific parameters as inputs and outputs in the DEA model (inputs: total revenue, academic staff, administration staff, total number of students; outputs: total number of publications, number of scientific articles, graduates). Different frontiers were developed, in terms of global and local regions. Also, the external factors affecting the degree of HEI inefficiency, e.g. institutional settings (size and department composition), location, funding structure were taken into consideration. It was found that the role of the university funding structure in HEI technical efficiency is different in Europe and in the U.S., thus making completely different influence in the end results. It is very interesting to note that regarding European units, more government funding is associated with greater inefficiency, while the share of funds from tuition fees decreases the efficiency of American public institutions, but relates to the efficiency improvements in European universities. Wolszczak-Derlacz, J. (2014)

One important step is overcoming the possible lack of comparable data when comparing the performance of higher education institutions. In some situations, it is impossible to be solved, regarding the current positions of the Universities and their development. Veiderpass and McKelvey are evaluating the performance of higher education institutions in a production theory context, applying the well-known data envelopment analysis (DEA) method to cross-section of 944 HEIs in 17 different European countries. It is pretty suitable to apply DEA in this context, where little is known about production technologies and economic behaviour of the HEIs. On average, provision of education is found to be most efficient in the Slovak Republic followed by Belgium and Latvia, while Denmark and Norway display the lowest efficiency. This study also indicated a positive relation between efficiency and HEI size and efficiency and research intensity. Furthermore, the study pointed to the importance of continued data collection. Veiderpass and McKelvey (2016).

Johnes and Johnes (2013) applied various stochastic frontier models and analysis in order to find and evaluate relative efficiency in English higher education institutions over the period 2003/04 to 2010/11. The stochastic frontier approach involves fitting a curve through data on costs and a variety of explanatory variables. In this way, they produced an envelope that defined an efficiency frontier – the best we can get with the resources available – a curve that shows the lowest possible costs at which a given set of outputs can be produced. The frontier is the benchmark against which the efficiency with which each institution produces its output can be determined. Once differences between institutions are accounted for 1, the variation in efficiency scores across institutions is greatly reduced, with a concentration of scores above 0.9 (where a score of one represents efficiency). Indeed, the relatively small number of institutions with low scores is exclusively made up of small and specialist institutions. The results do not, therefore, support the notion that substantial sector- wide gains could be made by using efficiency scores as a criterion for resource allocation.

Kulshreshtha and Nayak (2015) examined the technical efficiency (TE) of eight famous higher technical educational institutions (HTEIs) in India (more precisely, seven Indian Institutes of Technology (IITs) and Indian Institute of Science (IISc)), with appliance of SFA method (Stochastic Frontier Analysis) and DEA method (Data Envelopment Analysis). The study uses the input-oriented and output oriented stochastic distance function models, as well as constant returns to scale DEA approach to measure the TE of the above institutions. This paper demonstrates that technical efficiency definitely can varies between the examined institutions and points directly the need for strengthening the know-how (concerning higher technical education) of the Indian HTEIs, so that they can exploit the full potential of the existing educational inputs.

For sure, this is only a short list of the available papers and works regarding the issue. A great number of them show that DEA and SFA are probably the most widespread methods to evaluate relative efficiency of the higher education institutions, no matter whether it is in developed or in countries in developing. Normally, there are pros and cons regarding the methods also, but the results are pretty acceptable regarding the policy makers.

Evaluation methods

Creating the production frontier points the benchmark institutions in the sector. All the others institutions can follow the benchmarks in order to improve their relative efficiency. In this context, SFA and DEA are frontier analysis and can be applied for good enough results. So, the question is what method of constructing the production frontier and calculating the efficiency scores to be used

Using SFA in higher education needs a cross-section or a panel sample of HEIs. For the panel sample it does not require the condition of balance. For the production function it requires the quantitative data about inputs and output, for the cost function – a quantitative data about inputs and output, and the data about prices of products. For sure, we can examine both advantages and disadvantages of SFA:

Advantages:

(a) It enables to take into account a certain kind of random error and, simultaneously, to estimate the element of inefficiency.

(b) The influence of other factors can me modeled (quality, environment, etc.).

(c) Significance tests are in the base (sensitivity, resampling, bootstrapping, asymptotic theory).

(d) Change in efficiency can be decomposed into components: the change of technical efficiency, technological change, scale change.

Disadvantages:

(a) It requires an assumption about the functional form of the model and determination of the production technology.

(b) It requires assumption about the functional form of placement of the error term and inefficiency.

(c) In the analysis of the production function it can considers only one output indicator.

(d) In the analysis of the distance function it is difficult to explain obtained coefficients.

(e) In the analysis of the cost function it may be difficult to get exact prices for inputs.

(f) It is difficult to calculate.

As we can see, there are multiple disadvantages in terms of appliance SFA in the process of measuring the technical efficiency of HEIs.

DEA as well as the SFA is a frontier method. DEA uses linear programming methods to construct non-parametric piecewise surface (frontier) for a sample of HEIs, and the calculation of the efficiency with respect to this surface. DEA methodology is based on the approach of piecewise-linear convex envelope to calculate the frontier. Maybe one of the most important moments in DEA development and appliances through years was the publication of an article by A. Charnes et al. (1978). DEA term was used for the first time, using model of linear programming to solve the problem of frontier constructing and efficiency estimation. From that moment on, this method has received recognition and development.

DEA has the following advantages:

(a) it gives an opportunity to include in a model few inputs and outputs that allows estimating efficiency without calculation of a sole parameter of input or output;

(b) absence of necessity to choose the functional form of production function;

(c) it allows to analyse the efficiency in cases when it is difficult enough formally to explain relation between numerous resources and outputs of industrial system;

(d) it enables to estimate the contribution of each of inputs to overall efficiency (or inefficiency) of the companies and to estimate a level of inefficiency of each input;

(e) and besides an estimation of technical efficiency, it enables to estimate other kinds of efficiency, for example, economic efficiency.

Disadvantages:

(a) It does not provide a test for errors, i.e. DEA assumes that the errors in the original data are not available.

(b) The sensitivity of results to the number of variables in the model and number of observations, i.e. when the number of factors in the model increases and the number of observations decreases, then the number of HEIs that lie at the efficiency frontier increases.

Bearing the previous sections, we can determine that SFA can perform better if we deal only with one input, if there is a need to decompose efficiency into main components and it is important to measure various factors influence on HEIs' efficiency. In other cases, the DEA is better for evaluating efficiency. However, in order to use DEA for HEIs efficiency analysis we must be sure that our sample has enough data and this data doesn't have errors. So, the data and its grouping is very important.

MATHEMATICS OF THE PROPOSED TECHNIQUES

DEA technique

Modeling of the real word in DEA terms means having: Set of production units – input/output systems – known as DMUs (Decision Making Units), in this examination – university study program courses;

- Input parameters (same for all DMUs), in this examination investments for each course;
- Output parameters (same for all DMUs), in this examination the results of study program conduction in terms of knowledge and skills gathered from the students;
- Technical efficiency (the goal of the examination) of a single DMU is defined as:

$$\theta = \frac{Output}{Input}$$

It is called ***Pareto*** efficiency in case of best resources allocation (usually inputs) in the examined set of DMUs. The DMU with Pareto efficiency is called **efficient** DMU (in this paper – efficient course). The other DMUs are relatively inefficient (only in the observed set of DMUs). It is not possible for the efficient DMUs to change something in order to achieve better performances to the efficient DMUs (it is impossible to improve the output without worsening the input).

Having n DMUs with m inputs and s outputs each, the efficiency of k-th DMU is:

$$\theta_k = \frac{u_1 y_{1k} + u_2 y_{2k} + \cdots + u_s y_{sk}}{v_1 x_{1k} + v_2 x_{2k} + \cdots + v_m x_{mk}}$$

where $x_{1k}, x_{2k}, \dots, x_{mk}$ are the inputs of the k-th DMU, $y_{1k}, y_{2k}, \dots, y_{sk}$ are the outputs of the k-th DMU, $v_1, v_2, \dots, v_m$ are inputs' weight coefficients and $u_1, u_2, \dots, u_s$ are outputs' weight coefficients, with mathematical limitation (in connotation of the reality):

$$v_1, \dots, v_m \geq 0, u_1, \dots, u_s \geq 0,$$

In this paper, we use DEA CCR CRS input oriented model:

- Goal:

$$max\ (\theta_k = \frac{u_1 y_{1k} + u_2 y_{2k} + \cdots + u_s y_{sk}}{v_1 x_{1k} + v_2 x_{2k} + \cdots + v_m x_{mk}}),$$

- Limitations:

$$\frac{u_1 y_{11} + u_2 y_{21} + \cdots + u_s y_{s1}}{v_1 x_{11} + v_2 x_{21} + \cdots + v_m x_{m1}} = \frac{\sum_{i=1}^{s} u_i y_{i1}}{\sum_{j=1}^{m} v_j x_{j1}} \leq 1$$

$$\dots$$

$$\frac{u_1 y_{1k} + u_2 y_{2k} + \cdots + u_s y_{sk}}{v_1 x_{1k} + v_2 x_{2k} + \cdots + v_m x_{mk}} = \frac{\sum_{i=1}^{s} u_i y_{ik}}{\sum_{j=1}^{m} v_j x_{jk}} \leq 1$$

$$\dots$$

$$\frac{u_1 y_{1n} + u_2 y_{2n} + \cdots + u_s y_{sn}}{v_1 x_{1n} + v_2 x_{2n} + \cdots + v_m x_{mn}} = \frac{\sum_{i=1}^{s} u_i y_{in}}{\sum_{j=1}^{m} v_j x_{jn}} \leq 1$$

$$v_1, \dots, v_m \geq 0, u_1, \dots, u_s \geq 0;$$

$$x_{ij} \geq 0, y_{rj} \geq 0;\ i = 1, \dots, m;\ r = 1, \dots, s;\ j = 1, \dots, n.$$

The result are weights that maximizes each DMU's efficiency in respect of all the other DMUs, forming frontier line consisted of best DMUs with efficiency = 1 (**efficient DMUs)**. All inefficient DMUs have efficiency below 1 and are called **inefficient**.

Often, as in this paper, the dual DEA CCR model is used:

- Find $min\theta$
- Having limitations:

$$\sum_{j=1}^{n} \lambda_j x_{ij} \leq \theta x_{i0}, \qquad i = 1, \dots, m$$

$$\sum_{j=1}^{n} \lambda_j y_{rj} \geq y_{r0}, \qquad r = 1, \dots, s$$

$$\lambda_j \geq 0, \qquad j = 1, \dots, n$$

index 0 is for each DMU that equitations are solved for separately (in order to maximize its efficiency), lambdas represent weighted coefficients that build the composite DMUs for each inefficient DMU (shows possible ways for improvement). The composite DMU for each inefficient real DMU is consisted as sum of the ERS (efficiency reference set – efficient DMUs) multiplied with its lambda coefficients. If A and B are efficient DMUs (m inputs, s outputs) and belong to the ERS set of observed inefficient C DMU, the composite DMU C' can be calculated as:

SFA technique

In general, the frontier specifications we consider are variants of the general panel-data regression model:

$$y_{it} = \alpha_t + x_{it}\beta + v_{it} - u_{it} = \alpha_{it} + x_{it}\beta + v_{it} \,,$$

where y_{it} is output for firm i (i = 1,...,N) at time t (t = 1,...,T), x_{it} is a vector of inputs and v_{it} is a random error. In contrast to v_{it} , u_{it} is a one-sided error ($u_{it} \geq 0$), capturing the shortfall of y_{it} from the frontier, ($\alpha_t + x_{it}\beta + v_{it}$), The term “stochastic frontier” follows from the fact that the frontier specification includes v_{it}. Defining $\alpha_{it} = \alpha_t - u_{it}$, we have a model in which inefficiency is reflected in differences between firms in the intercepts. Various special cases arise depending on the restrictions placed on the α_{it}. The early literature on SFA developed in a pure cross-section (T = 1) context, where identification requires strong assumptions about the distributions of v_i and u_i.

The application and extension of panel data econometrics to SFA grew out dissatisfaction with these assumptions. The first panel frontiers treated inefficiency as a time-invariant firm effect, $\alpha_i = \alpha - u_i$. Estimates of the α_i can be obtained using standard panel techniques and converted into estimates of inefficiency. The time-invariance restriction can substitute for the distributional assumptions necessary for cross-section SFA. Later work on panel frontiers introduced specifications for the α_{it} that relax the time-invariance assumption, while retaining the advantages of panel data.

In general, when we say that a firm produces efficiently, we mean this in both a technical and allocative sense. Here our emphasis will be on technical efficiency, but we will pay some attention to allocative efficiency as well, in both cases following the canonical approach to the measurement problem developed by Farrell (1957). A firm is technically efficient if it uses the minimal level of inputs given output and the input mix or produces the maximal level of output given inputs.

The first definition is formalized in Farrell’s input-based measure, $I(y, x) = \min[b : f(bx) \geq y]$, (21.2) where I indicates the proportion of x necessary to produce y, holding the input ratios constant, and f is a standard, neoclassical (frontier) production function. This measure is illustrated in Fig. 21.1, which depicts an inefficient firm producing output y^A with input vector x^A. Technically efficient production occurs along the isoquant, $\mathrm{Isoq}[L(y^A)] = [x : I(y^A, x) = 1]$, where $L(y)=[x : (y, x)$ is feasible$]$ is the input requirements set. Because only bx^A is required to produce y^A, both inputs must be scaled back by the factor $(1-b)$ to achieve technical efficiency. While this measure is used widely, its appeal diminishes when the input set is not strictly convex (the isoquant is not everywhere downward sloping).

For example, the input vector x^B is technically efficient according to the Farrell input measure, although the same level of output could be produced with less of x_1. In this case, a distinction exists between the isoquant and the efficient subset, $ES[L(y^A)] = [x : x \in L(y^A)$, and $\tilde{x} \leq x$ implies $\tilde{x} \notin L(y^A)]$, with $ES[L(y^A)] \subseteq \mathrm{Isoq}[L(y^A)]$. In most econometric specifications this distinction has no practical significance, because the

$$\mathcal{O}(y, \mathbf{x}) = \min\left[a : f(\mathbf{x}) \geq \frac{y}{a}\right]$$

functional forms used in empirical work impose equivalence between the efficient subset and the isoquant. Corresponding to the output-oriented definition of efficiency is Farrell’s outputbased measure:

Holding inputs constant, 1/ gives the amount by which output could be expanded. From the perspective of the output-based measure, the firm producing yA with xA in the first equation will also be technically efficient if it operates on Isoq[L(yA/a)]. F¨are and Lovell (1978) showed that if f is homogeneous of degree r (r = returns to scale), then y = f(bx) = br f(x) = a f(x) and a = br . Thus, I = only under constant returns. When technology is not homogeneous, there is no straightforward interpretation of in terms of I, a result that has some implications for how technical efficiency is estimated. A firm is allocatively inefficient when the marginal rate of substitution between any two of its inputs is not equal to the corresponding input price ratio. This is true of the firm using xA in the first equation, instead of the cost-minimizing input vector x∗. Let p be the input price vector corresponding to the isocost line through x∗. Then the (input-based) technical efficiency of the firm producing with x^A is b = p' (bx^A)/p'x^A, and since p' x∗ = p' x^C, its allocative efficiency is the ratio p' x^C/p'

(bx). It follows that total or cost efficiency of the firm is given by p' x^C/p' x^A, or the product of technical and allocative efficiency.

The basic SFA empirical framework begins with the Farrell output-based technical efficiency measure, which relates observed output, yi, to the production frontier, f(xi; β), as follows:

$$yi = ai\ f(xi; \beta),\ 0 < ai \leq 1$$

The basic empirical framework for SFA is a regression specification involving a logarithmic transformation of this equation that adds a random error term (vi), as in:

$$\ln yi = \ln f(xi; \beta) + vi - ui$$

where ui = −lnai ≥ 0 represents technical inefficiency and output is bounded from above by the stochastic frontier f(xi; β)exp(vi). The output-based measure of technical efficiency is obviously recovered as exp(−ui). The vi serve the same purpose as any conventional regression disturbance—to account for random unobserved factors. The central econometric issue in models like this is how to treat the ui. With cross-section data they are usually assumed to follow some non-negative distribution, conditional on xi. Panel data afford the opportunity to view this model as a standard unobserved-effects model and avoid the distributional assumption. Other issues, such as choosing a functional form and the specification for f(xi; β), are also important insofar as they affect the estimation of firm efficiency.

Evaluation data

If the idea is to apply DEA technique, a large and a valid database (accurate and without errors) like EUMIDA European University Data Collection is necessary to be available, with as much as it is possible indicators about HEIs' indicators can be found in. Globalization and the knowledge-based society have driven universities to an intense competition for the best professors, researchers and students. Rankings and reports measuring how universities perform are available in abundance are also broadly available. Nevertheless Data Envelopment Analysis (DEA) have risen considerably since 1980s, there is a lack of consensus when selecting the indicators that represent the inputs and outputs of such institutions in a best way. In the following, we show an exhaustive review of the indicators used in DEA empirical studies in the last decade, classifying them according to their nature and use. We tried to systematize the main approaches to the data selection for DEA separately for inputs and outputs.

Inputs - It appears that practically all sets of inputs are mixed and have quantitative and cost nature. Such mixes are possible in DEA, and researchers actively used this advantage. We found very poor usage of quality indicators in inputs sets. It can be explained by quantitative and cost nature of the HEIs' resources – table 1.

Outputs - Outputs should reflect the results of the HEIs. We systematized output variables and approaches in the Table 2. Unlike inputs sets, we found many outputs sets with mixed as well as quantitative nature. Overall, in all outputs sets, the quantitative variables dominate.

Table 1

Inputs (Variables)	Approach
Number of academic staff Number of non-academic staff Non-labour expenditures Number of students	Mixed (quantitative and cost)
Total Funding per student Total Expenditure per student Academic Staff per Student	Mixed (cost and qualitative)
Number of full-time academic staff Operating Expenditures	Mixed (quantitative and cost)
Total number of students Number of academic staff Expenditure	Mixed (quantitative and cost)
Number of non-academic staff Number of academic staff Personnel expenditure Non-personnel expenditure	Mixed (quantitative and cost)
Academic staff Total revenue Number of students	Mixed (quantitative and cost)
Central government budget appropriations Own revenue Number of scientific research projects Number of academic staff	Mixed (cost and quantitative)
Number of students enrolled in Letter Number of students enrolled in Computer Sciences Media and Telecom	Quantitative

Table 2

Outputs (Variables)	Approach
Number of graduates Total amount of research grant Rate of success (Ratio of number of students who passed the exam to number of students who sat for the exam)	Mixed (quantitative, cost and qualitative)
Total graduate students Total PhD degrees awarded Total number of courses	Quantitative
Number of students Number of ISI publications Operating income	Mixed (quantitative and cost)
Number of graduates Total amount of external grants and contracts for research	Mixed (quantitative and cost)
Total degrees ISCED 5 Total degrees ISCED 6 PUB Number of published papers International collaboration Normalized impact High quality publications Excellence rate	Mixed (quantitative and qualitative)
Number of graduates Number of publications indexed in Web of Science	Quantitative
Number of graduates per academic Number of post-graduates per academic Number of doctorates per academic Number of publications Number of students graduating who are employed	Quantitative
Number of research units and laboratories Number of graduates from fundamental and applied license	Quantitative

Conclusion and discussion

This study is about the future in terms of what needs to be improved and changed for having better educational systems. For sure there is a need of common approach and unification of the data sets in terms of inputs and outputs, if we want to understand the higher education systems efficiency in different countries around the world. The variables in different researches sometimes coincide, but not always. Creation of a unified performance evaluation system for higher education is very hard, especially due to the dual nature of some total indicators of HEIs' work, where the same indicator can be considered as an input and as an output. Therefore, this dualism explains the lack of a unified approach to the selection of indicators to evaluate the efficiency of HEIs. Moreover, each country has adopted its own database of higher education indicators, so it is not possible at this moment to find the exact type and proportions of data in our country as it is in EU. Hence, evaluation of efficiency in our HEI depends on the reliable data, which can have both quantitative and qualitative nature. We found the most appropriate methods for performance evaluation of higher education – SFA and DEA. Moreover, SFA is more appropriate if we have only one output, need to decompose efficiency into main components and need to model the influence of various factors on HEIs' efficiency. In other cases the DEA is better for evaluating efficiency. However, in order to use DEA for HEIs efficiency analysis we must be sure that our sample has enough data and this data doesn't have errors.

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